Предметом дослідження є розробка технології експрес діагностування тягових передач електропоїздів. У її основу покладені оригінальні підходи щодо фрактального аналізу віброакустичних сигналів. Створено метод виділення акустичних складових (сэмплів), а також очистка їх від шуму. Як діагностичний параметр запропонований фрактальний показник Херста. Визначені діапазони його зміни. Це дозволяє оцінювати технічний стан тягових передач і прогнозувати їх працездатність в експлуатації

Ключові слова: віброакустичний сигнал, зубоспівспадіння, показник Херста, семпл, тягова передача, експрес діагностика, електропоїзд

Предметом исследования явилась разработка технологии экспресс диагностирования тяговых передач электропоездов. В ее основу положены оригинальные подходы по фрактальному анализу виброакустических сигналов. Создан метод выделения акустических составляющих (сэмплов), а также очистка их от шума. В качестве диагностического параметра предложен фрактальный показатель Херста. Определены диапазоны его изменения. Это позволяет оценивать техническое состояние тяговых передач и прогнозировать их работоспособность в эксплуатации

Ключевые слова: виброакустический сигнал, зубосовпадение, показатель Херста, сэмпл, тяговая передача, экспресс диагностика, электропоезд

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DESIGNING THE TECHNOLOGY OF EXPRESS DIAGNOSTICS OF ELECTRIC TRAIN'S TRACTION DRIVE BY MEANS OF FRACTAL ANALYSIS

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1. Introduction

For the transfer of power in electric trains, there is a special traction drive when electric motors are used for traction, the rotation of anchor of which is transferred directly to the leading wheel pair.

It is necessary to note that the traction drive relates to those units whose reliability directly influences safety of the motion of trains. Thus, for instance, the defects, not discovered in it in proper time, can lead to mechanisms breakdown, dropping their elements on the railway line and, as a result, to its damage, which can lead to significant material costs. This can also present threat for life and human health. For this very reason, in all locomotive depots, this unit is periodically checked and controlled.

The access to the traction drive in operation and during maintenance is hampered because of its design features, which creates specific problems in determining its technical condition. All this requires implementation of the modern systems methods and technical means for obtaining relevant objective data about its working capacity. They, first of all, should include vibroacoustic diagnostics, which makes it possible, without dismantling this mechanism, to obtain a signal that contains all necessary information about technical condition of traction drive.

At the same time, detection of defects of the toothed wheels of traction reducer based on acoustic signals and the technique of analysis of audio signal in its essence and according to applied methods is a multifaceted problem, which is up to now has not been solved in full. This, in turn, allows us to speak confidently about the relevance of this area of studies, which includes designing comprehensive technology of express diagnosis of traction drives based on fractal analysis.

2. Literature review and problem statement

At present, there is a significant quantity of physical methods of nondestructive control, used in the practice of quality control of materials and products. Among them, special place is occupied by acoustic control, based on application of elastic vibrations, excited or occurring in the object of control [1]. The search in the Internet for the words “diagnostics, acoustic signals” returns more than 70 thousand references. Therefore, attracting a wide circle of specialists and diverse methods of studies particularly emphasizes that this problem is not solved. Among the most significant scientific publications on this problem, it is possible to highlight the following.

The paper [2] presents physical bases, methods and means of acoustic control – one of the most common and rapidly developing forms of nondestructive control. However, it does not clearly reveal the positions about the fact that nondestructive control and diagnostics are important constituents of the problem of safety. General considerations of technical diagnostics of traction drives are examined in the studies [3], and the properties of acoustic noise and vibration, used for their diagnostics, are also analyzed. Special emphasis is given to the analysis of spectral components of the obtained signal; however, specific criteria, according to which it is possible to determine technical condition of the object, are not defined. The article [4] examines problemss of acoustic diagnostics of machines, propagation of vibrational energy along machine constructions and methods of decreasing the levels of their noise and vibrations. At the same time, it does not fully explore the sources of origin and the reasons that caused them. The study [5] is devoted to examination of the methods of acoustic diagnostics. It implies the analysis of the noise signal, which is connected to the work of mechanism, but in practice, it does not reveal how it is possible to subsequently use it. The publication [6] addresses the vibroacoustic methods, used for measuring low-frequency and high-frequency oscillations of the systems and elements of transportation vehicles. However, it does not fully cover the approaches to predicting technical state. The paper [7] examines the method of processing the acoustic WAV-file on the computer. As a shortcoming, it does not give the application of wavelet decomposition of computer signal into correction coefficients, which does not make it possible to assess fully the level of its noisiness. The article [8] examined the frequency analysis of stationary acoustic signals, conducted with the aid of filters and based on the fast Fourier transformation. Statistical problems of separating the signals and interferences are given considerable attention to in the studies [9–12], while the paper [13] described the questions of their filtration, discreteness, as well as the properties of correlation functions. It is necessary to note that all the above-mentioned studies are based essentially on the spectral Fourier analysis. Their shortcoming is in the fact that obtained results allow describing only the frequency composition of the measured signal, without linking its components to a specific time interval. And this in turn does not provide the possibility to reliably predict the state of the studied object.

Recently, increasing interest is manifested in the search for the models of nonlinear (chaotic) behavior of the signals, which can capture very sophisticated dynamic processes [14]. In this sense, the most adequate mathematical apparatus for exploring the dynamics and structure of such processes is the fractal analysis [15]. Its special importance lies in the fact that it is capable to consider the behavior of a system not only in the period of measurements but also in its prehistory [16–17]. As an example in this direction, it is possible to note the studies with application of fractal analysis in geology [18], medicine [19], chemistry [20], physical sciences [21], computer graphics [22] and seismography [23]. However, they as a rule do not cover in detail the properties of the persistence of the obtained time series, determining the noisiness of the studied dependencies and the differences that are not clearly expressed in the application of the Hurst index from other statistical methods.

Thus, the fractal analysis of time series, to which we propose to include the obtained and purified of noise vibroacoustic signal, is the solution of the complicated comprehensive scientific and technical problem, for which we designed the presented technology. This served, in turn, as a starting point for the application of this direction for the express diagnostics of traction drives of electric trains.

3. The purpose and objectives of the study

The purpose of the studies is the development of new technology for the express diagnostics of the traction drives of electric trains based on the methods of fractal analysis. It must determine in minimum time their working capacity and estimate the technical condition between the regular planned maintenance works.

To achieve the set goal, the following problems were defined:

– to conduct the studies of working capacity of the limiting units of electric trains and to define the main characteristic failures, which occur between the planned regular maintenance works in the process of operation;

– to determine the role of traction drive of electric train, to carry out the analysis of its working capacity, as well as the reasons for occurrence of its characteristic defects during operation;

– to design the method of determining basic parameters of the start of countdown and duration of the obtained vibroacoustic signal without dismantling a traction drive;

– to carry out tresholding and restoration of the noised vibroacoustic signal with the aid of existing computer software;

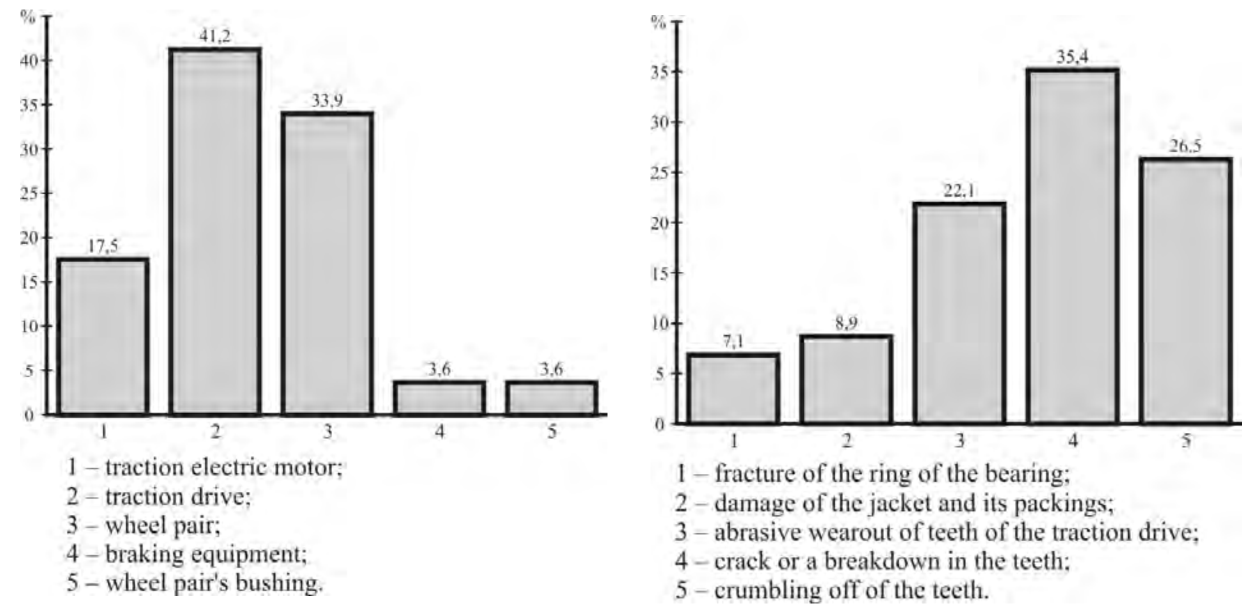
– to run the fractal analysis of the obtained vibroacoustic signals and to estimate their predictability according to the revealed defects in the traction drives of electric trains;

– to perform experimental studies and to confirm the adequacy of the obtained results.

4. Analysis of the failures of traction drives in operation

Talking about the failures of the equipment of electric trains, it is necessary to note that the traction drives, on par with wheel pairs, traction electric motors and electrical units, occupy one of the first places in terms of their failures. To confirm this, in 2014 we inspected technical condition of electric trains in the motor wagon depots of the Kharkov Southern Railroad, Ukraine (26 eight-wagon trains) and the Fastov Southwestern Railroad, Ukraine (34 eight-wagon trains). A commission inspected each wagon of electric train during planned technical inspections and regular repairs, with compiling aproppriate documents, which registered all malfunctions revealed for each case. Later on, all collected statistical data sets on the failures of the units of electric trains during this period was systematized and categorized according to the type of equipment. The results of the conducted research are given in the diagrams (Fig. 1).

As can be seen from the diagram (Fig. 1, *a*), the share of defects in the traction reducers is the most significant and amounts to 41,2 % relative to the total number of failures in the carriage part of electric trains. The deeper analysis made it possible to reveal the most frequently appearing failures of traction drive (Fig. 1, *b*), which are revealed during conducting regular maintenance. They must necessarily include the partial or complete wearout of teeth, chippings and chips caused by formation of fatigue cracks, crumbling off of working surfaces, crack or breakdown of the teeth.



a *b*

Fig. 1. Diagram of distribution of failures of electric trains: *a* — in the carriage part; *b* — in the traction drive

Thus, the problem emerges on the detection of these failures at the stage of their origin and, respectively, on forecasting the resource of traction drives in operation based on this.

5. Arrangement of the express diagnostics

When talking about the vibration control, it is necessary to note that today many locomotive-repairing enterprises possess modern powerful means of vibration control such as “Vector-2000” and “Prognoz-1” [3]. Their main purpose is the diagnostics and forecast of the service life of the rotation units such as the rolling and sliding bearings, rotors, couplings, gears, belts, impellers of flow-generating units, electromagnetic systems of electrical machines. However, the application of these devices in the scheduled works of maintenance service TO-3 and operating repair TP-1 is practically impossible because of the significant amount of time for conducting the diagnostics compared to the electric trains’ downtime at it.

A new technology of obtaining vibroacoustic signal with its subsequent processing was developed for this purpose. Its essence is in the following.

Before starting measurements, wheel pair of the electric motor car of electric train is lifted with the aid of hydraulic jacks to a height of 5–7 mm above the head of the rail (Fig. 2).

After this, reduced voltage from the welding current circuit is fed to the traction electric motor, which is connected with the tested traction drive. The place of the signal output on the jacket of traction reducer is thoroughly cleaned. When a wheel pair startss steady rotation, the vibration pickup ANS-014 is applied to the jacket of traction reducer in the specified place and the vibroacoustic signal is recorded for several seconds by the digital dictophone. After recording of the vibroacoustic signal, it is uploaded to the computer for further processing.

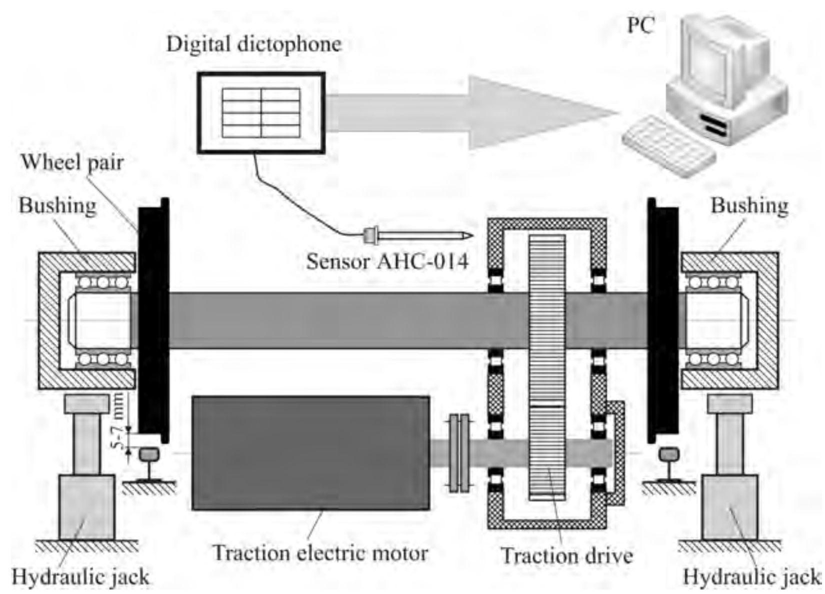


Fig. 2. Measurement scheme of vibroacoustic signal

6. Detection of basic parameters of vibroacoustic signal

Important task at the initial processing of vibroacoustic signal is determining the moment of its countdown start and its duration. The problem was set to determine the moment when the countdown of the received signal begins and how long it must last so that the information for the subsequent processing and analysis would be the most complete. The special method was developed for this purpose, which comes down to the following.

Since the full vibroacoustic signal is cyclic, (i. e., with each rotation of the large gear, its components repeated cyclically), then it was decomposed into separate equal sections. These sections are proposed to be identified with the samples that are used in the theory of music [7]. In this case, all components of complete vibroacoustic track-signal are repeated in each chosen sample.

The duration of a reference sample is proposed to be determined based on the frequency of alignment of teeth of the gear and gear wheels of traction reducer. This magnitude is defined as the frequency, with which specific tooth of the large gear is aligned with the specific gear tooth. This process is shown in Fig. 3.

Initially we determined coefficient of tooth alignment by the following empirical formula

$$k_z = \frac{z_1 \cdot z_2}{q^2}, \tag{1}$$

where z_1 and z_2 are the number of teeth of the large and small gears of traction reducer, respectively; q is the lowest common multiplier of the numbers of teeth, which for the traction reducers of electric trains ER2 and ER2T was accepted as q=10.

The computed value of coefficient of tooth alignment for the traction reducer of electric train ER2 amounted to 16,79, and for electric train ER2T – 16,5.

The frequency of tooth alignment of the large gear of traction reducer, which is mounted on the axis of a wheel pair, is proposed to define as

$$f_z = \frac{n_{zk}}{k_z} = \frac{n_{kp}}{k_z}, \tag{2}$$

where n_{zk} is the frequency of rotation of the large gear of a traction reducer or a wheel pair n_{kp}, upon which it is mounted.

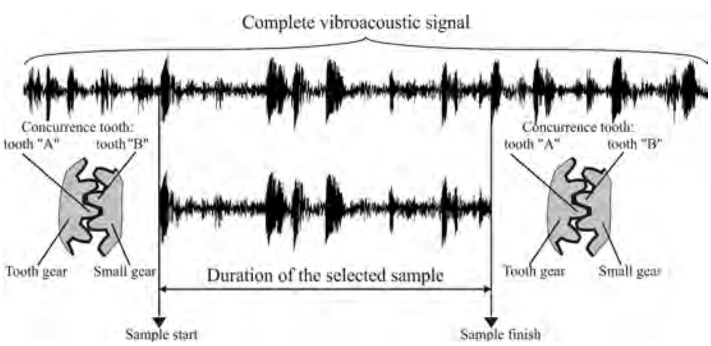


Fig. 3. Process of separation of the sample from the complete vibroacoustic signal

Then, if one knows the frequency f_z, it is possible to determine period T_z from the formula

$$T_z = \frac{1}{f_z}. \tag{3}$$

This magnitude of the period will determine duration of the chosen sample of vibroacoustic signal.

While conducting the tests, it was found that the frequency of rotation of a wheel pair is n_{kp} min^{-1}. As a result of this, for electric train ER2, the calculated duration of the chosen sample of vibroacoustic signal at the number of teeth of the larger wheel z_1=73 and the gear z_2=23 amounted to 8,39 s, and for electric train ER2T, at the number of teeth, respectively, z_1=75 and z_2=22, it reached 8,25 s.

For each traction reducer, in the course of the tests and picking up of the vibroacoustic signal in it, we selected up to 3–5 samples for their further processing and analysis.

7. Denoising the selected sample

The initial processing of the chosen sample implied its denoising from the components with the use of the wavelet conversion of "thresholding" [25]. In this case, the main model of the noisy chosen sample S(n) was represented as

$$S(n) = f(n) + e(h), \tag{4}$$

where f(n) is the useful signal; e(h) are the components of noise in the signal.

For denoising the chosen sample, we used the method that is well known from the technology of filtration, which consisted in the removal of high-frequency components from the spectrum of the signal [25]. With the help of wavelet conversion, this task was solved by the limitation of the level of detailing coefficients. The short-term peculiarities of signal (they may include noises in the form of the set of such peculiarities) create detailing coefficients with high content of the noise components, which have large random ejections of the values of signal. That is why the purpose of denoising was to suppress the noise part e(h) of the chosen sample and bring its restoration maximally to the orginal form.

The procedure of denoising the chosen sample was carried out with the use of the Matlab software package (the Wavelet Toolbox packet) and included three main stages [25]:

1. Selection of the reference wavelet and the level of its decomposition N, as well as the wavelet-decomposition to this level.
2. The implementation of detailing, during which a ceratin threshold for each level from 1 to N was selected and the threshold processing of detailing coefficients was applied.
3. The wavelet-restoration of the denoised signal, based on the original coefficients of approximation at the level N, as well as modification of detailing coefficients at the levels from 1 to N.

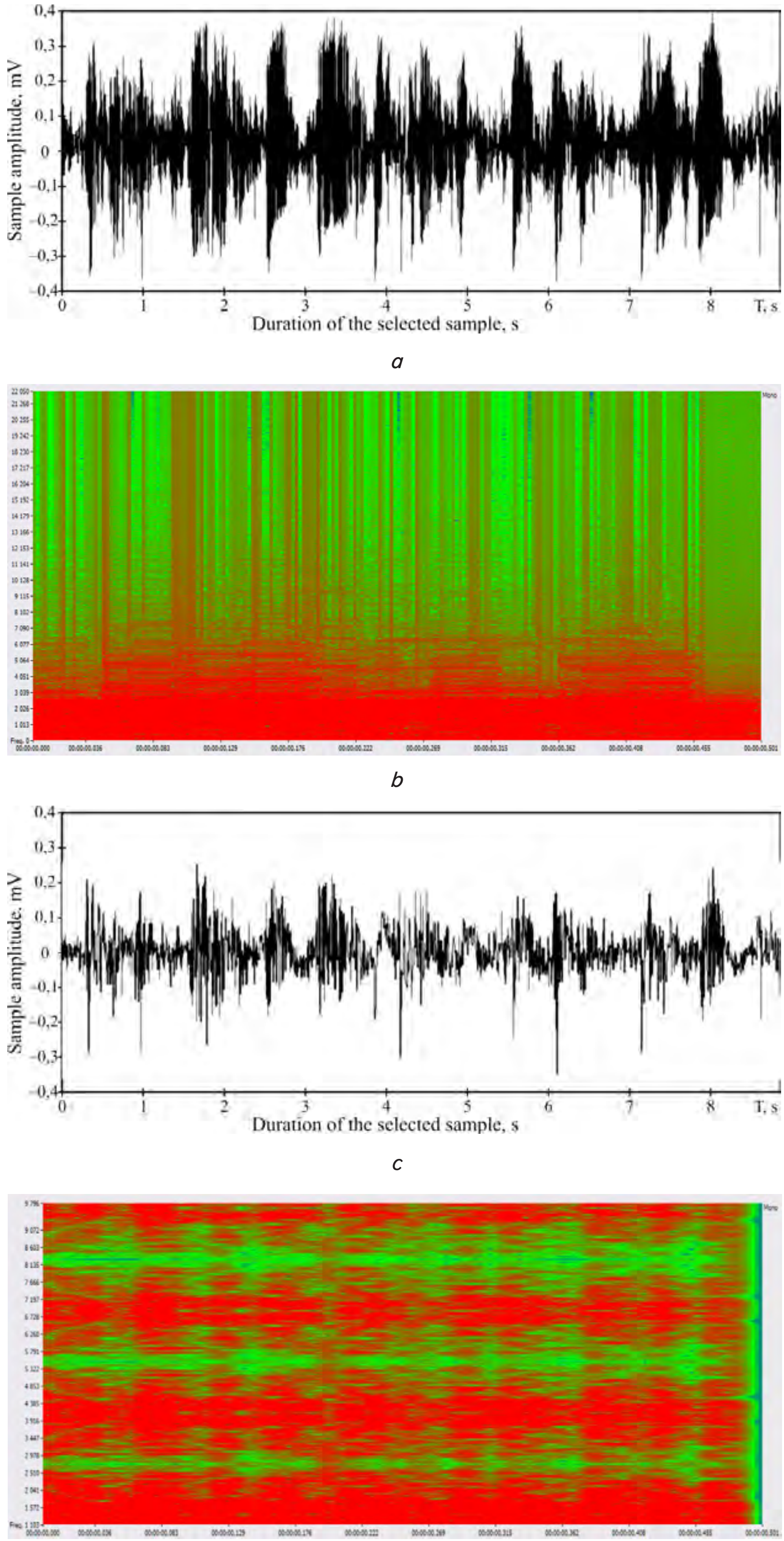
It is necessary to note that in the course of the wavelet analysis, the signal is decomposed into approximating coefficients, which present the smoothed signal, and the detailing coefficients that describe oscillations. Hence, a noise component is better reflected in the detailing coefficients. That is why, during denoising the chosen samples, only the detailing coefficients were processed.

Fig. 4 displays an example with the results of denoising of the chosen vibroacoustic sample.

For denoising the selected sample we used the simplest Haar wavelet due to its orthogonality and possibility of reconstruction of the signal. The decomposition of initial signal, for the purpose of the optimum ratio of the utilized computer resources (both in time and computation), was carried out restricted to the fifth level. The interval thresholds were selected automatically step-by-step on all levels.

The spectrogram (Fig. 4, *b*) vividly demonstrates the noise of green color, which takes up to 45 % of the entire area against the background of initial red noisy signal. After the denoising, one can clearly see that the magnitude of noise (Fig. 4, *d*) was considerably reduced while the share of the useful signal increased in the entire spectrogram.

Tresholding of the selected vibroacoustic samples during conducting the tests made it possible to considerably increase their informativeness and to decrease the error with subsequent calculations.



a

b

c

d

Fig. 4. Vibroacoustic samples and their spectrograms: *a* — sample with noise; *b* — spectrogram of sample before denoising; *c* — denoised sample; *d* — spectrogram of sample after denoising

8. Diagnostics of traction drives based on the fractal analysis

One of the most interesting directions in the development of the fractal methods of analysis and forecasting of time systems is the Hurst method, or the **R/S** method, which is also called the method of the adjusted range. This empirical method was proposed for statistical analysis of time series in the beginning of XXth century by Hurst [26]. This method of research is well known in the statistical practice of economics and finances [27]. However, in the technical sciences, its implementation is sometimes limited by the difficulties of physical interpretation. At the same time, the Hurst method, robust as it is, makes it possible to reveal in statistical data such properties as clustering, tendency to follow the direction of trend, strong aftereffect, strong memory, fast change in the sequential values, fractality, availability of periodic and nonperiodic cycles, capacity to distinguish "stochastic" and "chaotic" nature of noise, etc. In addition to the fundamental work of H. Hurst, the study of B. Mandelbrot played significant role in the development of the theory of the **R/S** method and its practical application [17]. It is based on the so-called method of the accumulated deviation (or the method of adjusted range). According to this method, not the sums of the data are analyzed that compose a dynamic time series, but the range of the sum of deviations of these data from the arithmetic mean, normalized by dividing by the standard deviation.

The sums of these deviations are calculated for different periods of time (or for different quantity of sequential moments of observations), which serve as the scale of measurement.

The main difference in the method of the adjusted range (or the R/S method of forecasting) from other existing statistical methods for the analysis of time series is in the fact that this method includes in its analysis a direction of time while other known methods are invariant with regard to this time.

The solution of the problem of the R/S method of forecasting based on the analysis of vibroacoustic signal is in the following. First of all, it is necessary to establish if the studied series is a fractal or simply a stochastic process. For this purpose, the fractal dimensionality D is determined as

$$D = 2 - H, \tag{5}$$

where H is the Hurst index.

If the obtained value D is fractional and larger than one (D>1), then it is possible to consider that the studied time series is fractal and possesses all necessary peculiarities for its fractal estimation.

The order of determining the Hurst index consists in the following. With regard to vibroacoustic signal, we assume that it represents time dependence y(t), with different values of magnitudes of amplitudes y during discrete integral moments of time t. Let us imagine that y is a certain accumulated magnitude and can be represented as the sum of some elementary contributions Δt in a certain limited range of time t from 1 to τ. Then the average value of time series is defined as

$$\bar{y}(\tau) = \frac{1}{\tau}\sum_{t=1}^{\tau}\Delta y(t) \tag{6}$$

or

$$\bar{y}(\tau) = \frac{y(\tau)}{\tau}. \tag{7}$$

The accumulated deviation of a series of measurements $\Delta y(t)$ is calculated after this from the mean $\bar{y}(\tau)$

$$y(t,\tau) = \sum_{i=1}^{t}\left[\Delta y(i) - \bar{y}(\tau)\right]. \tag{8}$$

Difference in the maximum and minimum values (range) of the process $y(t)$ in the time interval τ is determined as

$$R = \max_{1\le t\le\tau} y(t,\tau) - \min_{1\le t\le\tau} y(t,\tau). \tag{9}$$

Mean-square deviation of increases in the random process in the interval τ will reach

$$S = \sqrt{\frac{1}{\tau}\sum_{t=1}^{\tau}\left[\Delta y(t) - \bar{y}(\tau)\right]^2}, \tag{10}$$

where $\Delta y(t)$ is the elementary increase y(t) at step t.

Range is defined as the ratio

$$R/S = (a\cdot\tau)^H, \tag{11}$$

where a is the Hurst constant, determined a=0,5.

Then the obtained values take the logarithm of

$$\log\left(R/S\right) = \log(a\cdot\tau)^H = \\ = H\log(a\cdot\tau) = H\left[\log(\tau) + \log(a)\right]. \tag{12}$$

After this, using the substitution

$$\log(\tau) = \varphi \text{ and } H\log(a) = c,$$

the array is approximated by the linear dependence

$$f(\varphi) = H\cdot\varphi + c. \tag{13}$$

The Hurst index is found by determining the tangent of inclination of the straight line of this linear dependence.

Based on this, when conducting the studies, the vibroacoustic denoised signals in the WAV format were processed with the help of the freeware program Fractan 4.4 available in the Internet. The special feature of this program is the fact that the studied signals in the WAV format undergo special treatment in it and they are converted into integral numbers, which makes it possible to compute faster.

The Hurst index, obtained during calculations, for the vibroacoustic sample, from the point of view of assessment of the working capacity of a traction drive, can be interpreted as follows [26].

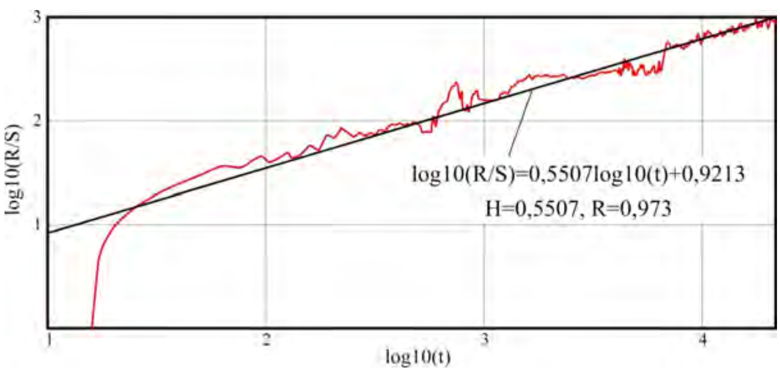
When finding the Hurst index in the interval 0<H<0,5, the values of the studied time series (sample) are not independent. Each of them stores memory about the preceding events. In this case, time is an important factor, which influences the entire system (traction drive as a whole). This range corresponds to the anti–persistent (ergodic) series, i. e., "the return to the mean". If time series demonstrates increase in the previous period, then its decrease will subsequently begin in the following, and so it is possible to expect the occurrence of failure.

With the value of the Hurst index H=0,5, the time series under consideration is the random movement. In this case, all values are random and are not correlated, i. e., the present does not influence the future (the system is in the indeterminate state).

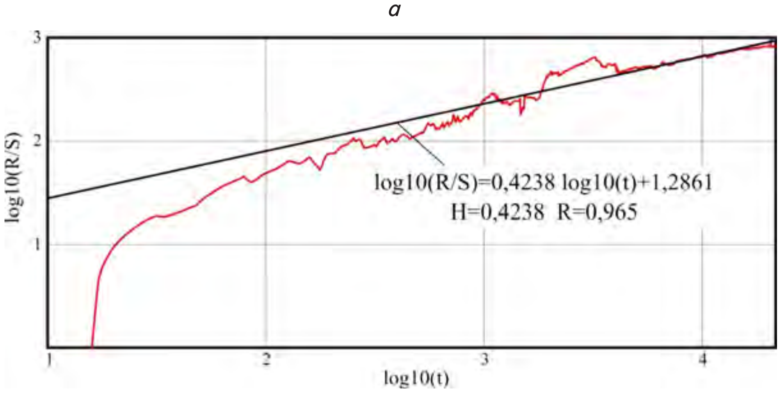
When finding the Hurst index in the interval 0,5<H<1,0, the value of the studied time series are dependent. Trend stability of the behavior of the values of the series (the force of persistence) increases with the values H approaching 1. In this case, the closer H to the value 0,5, the noisier is the series and the less its trend is expressed. If a series grows in the preceding period, then this tendency will be preserved in future, i. e., the occurrence of failure is not expected.

Fig. 5 displays the results of calculating the Hurst index in the Fractan 4.4 program for two denoised vibrodiagnostic samples (they are shown by red color).

From the obtained value of the Hurst index (Fig. 5, *a*), it is possible to make a conclusion that the studied vibroacoustic sample possesses fractality and is not the creation of purely stochastic process, since D=2–0,5507=1,4493. Therefore, this signal is subject to the fractal methods with the purpose of determining the optimum configuration of the forecasting systems. From the point of view of forecast, the value of the Hurst index exceeds the value 0,5 and that is why it is possible to draw a conclusion that in future this traction drive will preserve the set working capacity and the defects in it it are not likely.



a



b

Fig. 5. Results of calculating the Hurst index H: *a* — the index that is within the interval 0,5<H<1,0; *b* — the index that is within the interval 0<H<0,5

Results of calculating the Hurst index (Fig. 5, *b*) also confirm its fractality, since D=2–0,4238=1,5762. However, from the point of view of forecast, in this case the Hurst index is lower than the value 0,5 and it is possible to assume the origin of the defect in the unit, which subsequently may lead to the breakdown and complete failure of the traction drive.

9. Results of the studies on designing new technology of the express diagnostics of the traction drives

Based on the proposed technology, during the planned maintenance works TO-3 и TP-1, traction drives in the electric trains, which were in operation, were checked. The analysis of the technical condition of each traction reducer was evaluated according to the value of the Hurst index and its compliance with the accepted intervals. The express diagnostics was carried out in the motor wagon depot of the Kharkov Southern railroad during the first, second and third TO-3 after maintenance works of TR-2 on four chosen electric trains (one train has 16 traction drives). Totally, during the period of conducting the tests, we diagnosed 192 traction drives. According to the results of the majority of them (around 86 %), the calculated Hurst index was within the range of 0,56–0,65. This was accepted as the absence of any defects in them, and the electric train returned to operation. As an example, Fig. 6 displays the dynamics of distribution of the Hurst index for four traction drives, which belong to one electric motor wagon of electric train during regular maintenance works TO-3.

In this case, it is evident that all values of the Hurst index are within the interval 0,5<H<1,0 i. e., the occurrence of malfunction in these traction drives was not forecasted.

At the same time, as a result of conducting the experiment, some traction drives displayed significant defects, visually confirmed during dismantling.

Thus, on the electric train ER2R–7070 during the express diagnostics of three traction drives of electric motor wagons 70704, 70706 and 70708, before conducting TO-3, based on the processing vibroacoustic signals, the calculated Hurst index reached **H**=0,43÷0,48. The fractal dimensionality in this case comprised D=1,57÷1,52. During cranking, the traction drives produced loud noise in the low-frequency range. It was found by testing (with the help of regular probes) that their jackets almost ran out of lubricant. After filling them up to the required level, the vibroacoustic signals were taken again. The noise noticeably decreased and, according to the results of processing the signals, the Hurst index reached **H**=0,52÷0,54.

In two traction drives we obtained the Hurst index 0,44 and 0,41, respectively, and the fractal dimensionality was D=1,56÷1,59. When cranking the wheel pairs, knocks and bumps were heard. The chippings and cracks in the teeth of the crown of the large gear were discovered after dismantling the traction drives and their visual inspection through the inspection holes in the jacket. The electric motor wagon with these defects was sent for repair.

For some traction drives we received the calculated Hurst index within the range of **H**=0,36÷0,41 and the fractal dimensionality was D=1,59÷1,64. Their inspection found increased wearout of the surface of the teeth and, as a result, vilation of their geometry.

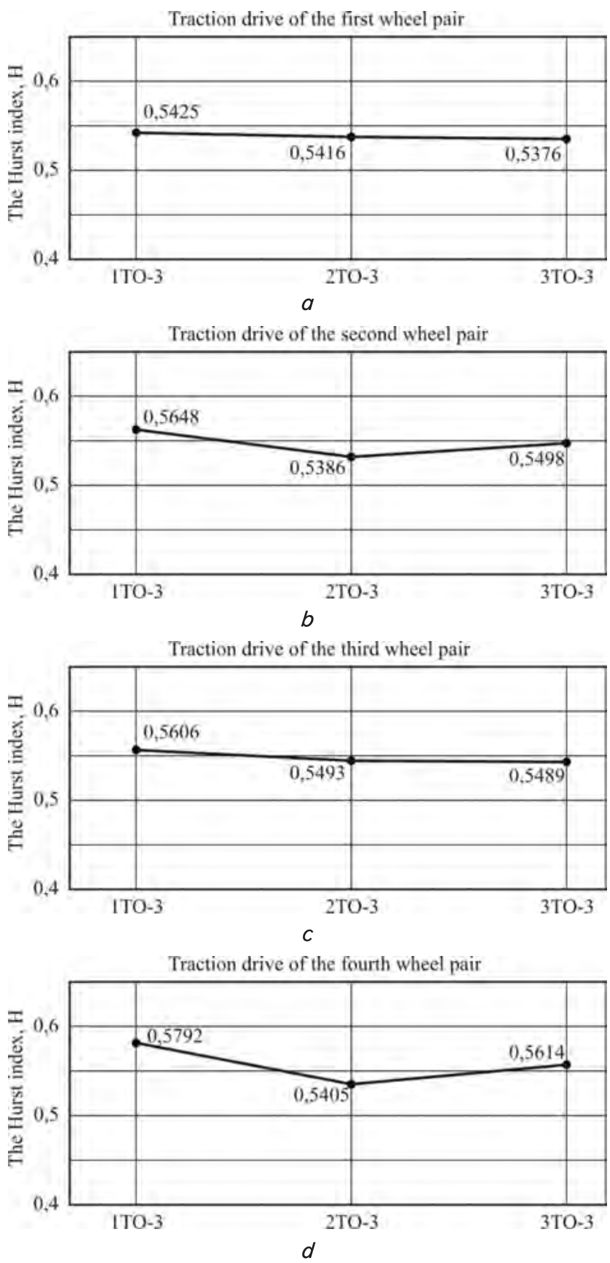


Fig. 6. Distribution of the Hurst index according to the results of diagnostics of the traction drives of one electric motor wagon during regular TO-3 of wheel pairs: *a* – the first; *b* – the second; *c* – the third; *d* – the fourth

In general, it is necessary to note that as a result of processing vibroacoustic signals during conducting of experimental studies, we always obtained fractional dimensionality D, which confirmed not the stochastic, but the fractal essence of the processes that occur in the traction drives of electric trains.

10. Discussion of the obtained results of express diagnostics of the traction drives

As a result of conducting experiment, each traction drive, for which, according to the calculated Hurst index, the unsatisfactory technical condition and the presence of defects was forecasted, was dismantled and checked. In this case, the micromeasurement of dimensions of the components was conducted, as well as the main reasons and factors that led to this defect were defined. Based on this, the main factors were determined, which cause wearout of traction drive. And it was found that there were many active factors and each of them might be considered the reason for the ocurred malfunction. However, those factors emerge, which define specific conditions of the carriage part performance, – dynamic loads both in the vertical and horizontal planes. The reasons for many failures are the low quality of maintenance work and repair of the critical units of mechanical part, absence of the overall application of effective methods of restoring the working capacity of the components during their repair. No less important is the role of the low maintainability of a number of parts of the traction drive. It was found that the traction drives of electric trains, especially those that underwent plant or depot repair, possessed increased level of vibration and noise that appeared as a result of cannibalization of toothed gears.

Furthermore, when conducting the studies, important circumstance proved to be the establishment of periodicity of the express of diagnostics of traction drives of electric trains. Based on the accumulated data set of the Hurst index H depending on the time period of operation T after TP-2, the following approximating dependence of the linear form is proposed

$$H = 0,065T + 0,3. \quad (14)$$

By this dependence, setting by calculated value of the Hurst index H, we proposed to determine the estimated interval of time (in months), after which it is necessary to repeat the express diagnostics of the given traction drive. Thus, if the calculated Hurst index at present is H=0,56, then the checking must be performed in 4 months, and if H=0,365, then the express diagnostics of the given traction drive must be carried out after each subsequent month of operation of electric train.

It was also found that in the case of evaluating the remaining resource, there is the possibility (with a certain lead) to forecast the technical condition of particular traction drive as a whole, depending on the operation conditions of the electric train.

11. Conclusions

1. We carried out studies of the failures of equipment of electric trains in operation, which showed that the share of defects in the traction reducers is the most considerable and amounts to 41,2 % of the total number of failures in the carriage part. They must include a partial or complete wearout of teeth, chippings and chips due to formation of fatigue cracks, crumbling off of working surfaces, cracks or breakdowns of teeth.

2. The role of traction drive is determined from the point of view of its working capacity and safety of motion. The processes are defined, which take place directly in the traction drive during conversion and transfer of power from the source to the engine, and the load that occurs in the course of motion of electric train. It was found that the traction drives, on par with wheel pairs, traction electric motors and electrical units, occupy one of the first places with regard to their failures.

3. We developed the method, based on selection of of cyclic components (samples) out of complete vibroacoustic signal. Its characteristic property is initial link to the time interval, determining its final duration, as well as selection of a number of cyclically repeated components with each rotation of the large gear. The duration of basic sample was determined in accordance with the proposed coefficient of tooth alignment, which takes into account a number of teeth of the wheel-gear and the gear and by the common multiplier, dimensionless for them. On its basis, we also proposed empirical dependences, which allow, in accordance with the defined frequency of rotation of a wheel pair, calculating both the period and duration of the selected samples for their subsequent analysis.

4. The tresholding (noise suppression) of the obtained vibroacoustic samples was executed. It implies the wavelet conversion of the sample, by restricting detailing coefficients and its subsequent restoration. For its implementation, we proposed to use widespread Matlab software that makes it possible for the user to perform wide selection and calculation of coefficients of thresholding for each level of the wavelet decomposition.

5. The fractal analysis of vibroacoustic samples was performed, which makes it possible to calculate the limit of their predictability in each specific case. As the main diagnostic parameter, we proposed the Hurst index, whose calculation shows that a vibroacoustic sample for the traction drives can relate to both the persistent and anti-persistent processes. The diagnostic ranges for evaluating the Hurst index are proposed, based on which it is possible to determine technical condition of traction drives, as well aspredict their working capacity in operation.

6. The experimental studies were conducted, which confirmed the fractal properties of the vibroacoustic samples and revealed that they can change in accordance with the discovered defects in the traction drives. In this case, it was confirmed that the method of R/S analysis is adequate enough for the evaluation of results of the express diagnostics and proved correctness of its application for monitoring the technical condition of traction drives. Characteristic failures in the traction drives and predictability of their manifestation based on the change in the Hurst index allowed us to recommend continuation of the given studies and to expand it to the entire fleet of electric trains.

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